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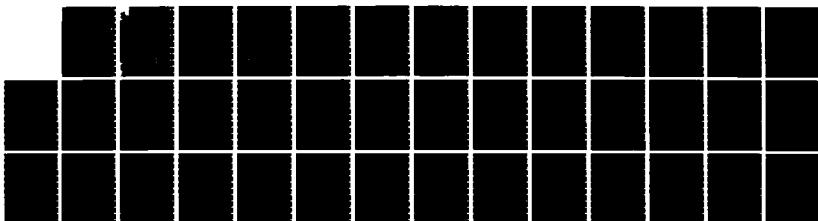
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INTERIM GUIDANCE FOR PRE. (U) ARMY ENGINEER WATERWAYS
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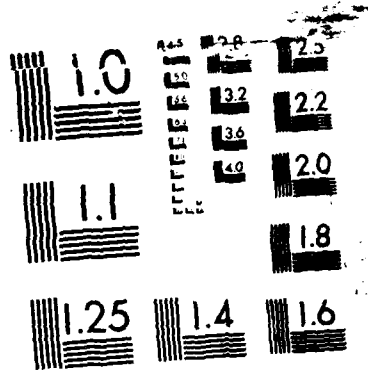
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LONG-TERM EFFECTS OF
DREDGING OPERATIONS

MISCELLANEOUS PAPER D-86-1

INTERIM GUIDANCE FOR PREDICTING THE
QUALITY OF EFFLUENT DISCHARGED FROM
CONFINED DREDGED MATERIAL
DISPOSAL AREAS

by

Michael R. Palermo

Environmental Laboratory

DEPARTMENT OF THE ARMY
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February 1986

Final Report

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<p>The quality of effluent from confined dredged material disposal sites (water discharged during active disposal operations) is an environmental concern when the sediments to be dredged are contaminated. Dredged material placed in a confined disposal area settles, while the clarified supernatant waters with some residual colloidal solids are discharged from the site as effluent. The effluent may contain concentrations of both dissolved and</p>		

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20. Abstract (Continued)

particle-associated (adsorbed or attached by ion exchange) contaminants. A large portion of the total contaminant concentration is, however, particle associated.

A modified elutriate test procedure to estimate both the dissolved and particle-associated concentrations of contaminants in confined disposal area effluents is discussed. The laboratory test simulates contaminant release under conditions prevalent in confined disposal areas and reflects sedimentation behavior of dredged material, retention time of the containment, and physico-chemical environment in ponded water during active disposal.

In the test, sediment and water from the dredging site are mixed to a slurry concentration equal to the expected influent concentration under field conditions. The mixed slurry is aerated in a 4-l cylinder for 1 hr to ensure oxidizing conditions will be present in the supernatant water. Following aeration, the slurry is allowed to settle under quiescent conditions for a period equal to the expected mean field retention time, up to a maximum of 24 hr. A sample is then extracted from the supernatant water and analyzed for total suspended solids, and for dissolved and total concentrations of contaminants of interest. The contaminant fractions of the total suspended solids may then be calculated.

Column settling tests, similar to those used for design of disposal areas for effective settling, are used to define the concentration of suspended solids in the effluent for a given operational condition, i.e. ponded area, depth, and inflow rate. Using results from both of these analyses, a prediction of the total concentration of contaminants can be made. The acceptability of the proposed confined disposal operation can be evaluated by comparing the predicted contaminant concentrations with applicable water quality standards while considering an appropriate mixing zone and the quality of the receiving water body.

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PREFACE

This work was conducted as part of the Long-Term Effects of Dredging Operations (LEDO) Program at the Environmental Laboratory (EL), US Army Engineer Waterways Experiment Station (WES), Vicksburg, Miss. The LEDO Program is sponsored by the Office, Chief of Engineers (OCE), US Army. This paper was written as part of Work Unit 31775, Techniques for Predicting Effluent Quality of Diked Containment Areas. The Technical Monitors were Drs. William L. Klesch and Bob Pierce of OCE and Mr. Charles W. Hummer of the Water Resources Support Center.

A potential environmental concern associated with confined dredged material disposal is the quality of effluent discharged during active disposal operations. Interim guidance for predicting the quality of effluent discharged from confined disposal areas is contained in this paper. The work was performed during the period October 1981 to December 1984 by Dr. Michael R. Palermo, Chief, Water Resources Engineering Group (WREG), of the Environmental Engineering Division (EED), EL. The work was performed under the general supervision of Dr. Raymond L. Montgomery, Acting Chief, EED, and Dr. John Harrison, Chief, EL. Managers of the LEDO Program within EL's Environmental Effects of Dredging Programs were Mr. Charles C. Calhoun, Jr., and Dr. Robert M. Engler. Technician support was provided during the course of the study by Ms. Cheryl Lloyd and Ms. Kathy M. Smart, EED. Mr. Anthony Gibson, EED, provided computer support. Technical review was provided by Dr. Edward L. Thackston of Vanderbilt University and Dr. Engler of EL. The report was edited by Ms. Jamie W. Leach of the WES Publications and Graphic Arts Division.

At the time of publication, COL Allen F. Grum, USA, was Director of WES and Dr. Robert W. Whalin was Technical Director.

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CONVERSION FACTORS, NON-SI TO SI (METRIC)
UNITS OF MEASUREMENT

Non-SI units of measurement used in this report can be converted to SI
(metric) units as follows:

<u>Multiply</u>	<u>By</u>	<u>To Obtain</u>
acres	4046.873	square metres
acre-feet	1233.489	cubic metres
cubic feet per second	0.02831685	cubic metres per second
feet	0.3048	metres
gallons (US liquid)	3.785412	cubic decimetres
inches	25.4	millimetres

INTERIM GUIDANCE FOR PREDICTING THE QUALITY OF EFFLUENT DISCHARGED
FROM CONFINED DREDGED MATERIAL DISPOSAL AREAS

PART I: INTRODUCTION

Background

1. Confined dredged material disposal has increased in recent years primarily because of constraints on open-water disposal of sediments classified as contaminated. The quality of effluent discharged during active disposal operations is a potential environmental concern associated with confined disposal.

2. A schematic of an active confined disposal area is shown in Figure 1. Dredged material placed in a confined disposal area settles, resulting in a thickened deposit of material overlaid by a clarified supernatant. The supernatant waters are discharged from the site as effluent during active dredging operations. The effluent may contain both dissolved contaminants and colloidal particles with associated (adsorbed or ion exchanged) contaminants. A large portion of the total contaminant concentration is particle associated.

3. Supernatant waters from confined disposal sites are discharged

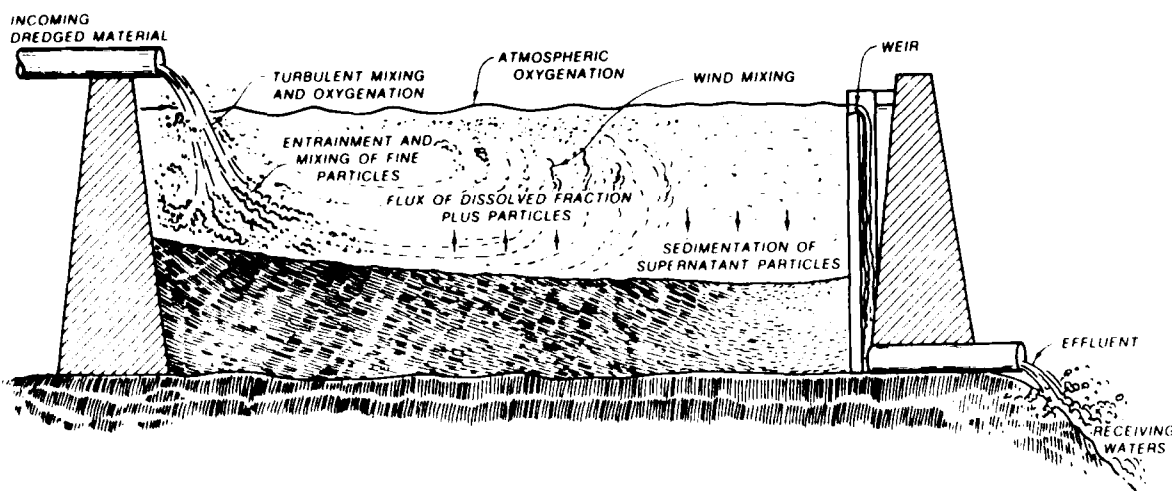


Figure 1. Schematic of supernatant water interaction in an active confined disposal site

after a retention time of up to several days. Furthermore, actual withdrawal of the supernatant is governed by the hydraulic characteristics of the ponded area and the discharge weir. Procedures have been developed to predict concentrations of suspended solids in disposal area effluents, taking into account the settling behavior of the sediment (Palermo, Montgomery, and Poindexter 1978). Several factors influence the concentration of suspended particles present in supernatant waters. Fine particles become suspended in the disposal area water column at the point of entry due to turbulence and mixing. The suspended particles are partially removed from the water column by sedimentation. However, particle concentrations may be maintained by flow of water through the slurry mass during settling. Wind and/or surface wave action may also resuspend additional particles. All solids cannot be retained during the disposal process, and associated contaminants are transported with the particles in the effluent to the receiving water.

Purpose and Scope

4. The purpose of this paper is to describe an interim technique for predicting the quality of effluent discharged from confined dredged material disposal sites. The technique provides an estimation of potential contaminant release under laboratory-simulated confined disposal conditions. The procedures used in the technique consider the sedimentation behavior of dredged material, the retention time of the proposed containment area, and the physicochemical environment in ponded water during active disposal into the containment area. Procedures for sampling, for conducting modified elutriate and column settling tests, and for analysis of the data are included.

5. Long-term geochemical changes may occur following disposal, site dewatering, and subsequent drying of the dredged material. The quality of the surface runoff from disposal sites after these long-term changes occur may be markedly different from that of the effluent discharged during active disposal. The technique described in this paper applies only to conditions during active filling of the site and does not account for long-term geochemical changes. Therefore, it should not be used to evaluate the quality of surface runoff.

6. The guidance contained in this report is the result of ongoing research conducted under the Long-Term Effects of Dredging Operations (LEDO)

Program. The procedures are now being verified under the LEDO Program through comparative evaluations of field data and laboratory predictions.

PART II: PREDICTIVE TECHNIQUE

7. The prediction of the quality of effluent from confined dredged material disposal areas must account for both the dissolved concentration of contaminants and for that fraction associated with the released total suspended solids. A modified elutriate procedure has recently been developed for this purpose (Palermo, in publication). This test defines dissolved concentrations of contaminants in milligrams per litre and contaminant fractions in the suspended solids (SS) in milligrams per kilogram SS under quiescent settling conditions and considers the geochemical changes occurring in the disposal area during active disposal operations. Refinements and extensions of column settling test procedures (Montgomery 1978; Palermo, Montgomery, and Poindexter 1978) have also been developed to define the concentration of SS in the effluent for a given operational condition (i.e. ponded area and depth, inflow rate, and hydraulic efficiency). Using results from both of these analyses, a prediction of the total concentration of contaminants in the effluent can be made. A flowchart illustrating the steps required to predict effluent quality is shown in Figure 2.

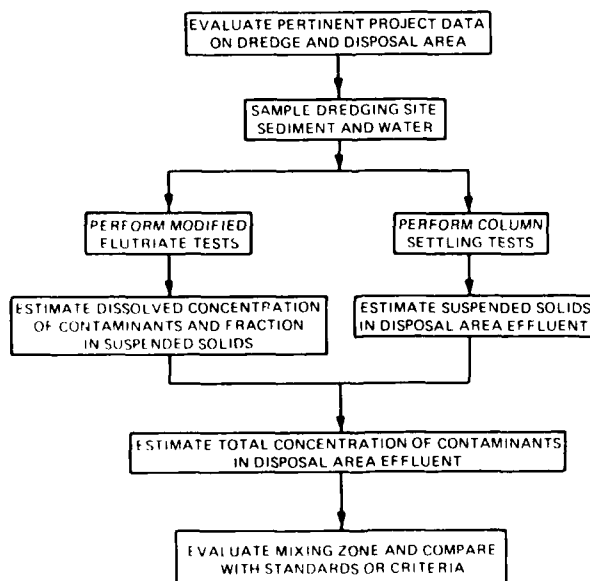


Figure 2. Flowchart illustrating steps required for prediction of the quality of effluent from confined dredged material disposal areas

8. The predictive technique can be applied to predict the performance of existing sites and to design new sites. For existing sites, the technique can be used to predict the effluent quality for a given set of anticipated operational conditions (known flow and containment area size). In a similar manner, the required operational conditions for a new site (size, geometry, maximum allowable dredge size, etc.) can be determined to meet a given effluent quality requirement by comparing the predicted effluent quality for a variety of assumed operational conditions.

Regulatory Aspects

9. Recent guidelines (Environmental Protection Agency (EPA) 1980a) have been published to reflect the 1977 Amendments to Section 404 of the Clean Water Act. Proposed testing requirements (EPA 1980b) define dredged material according to four categories, as shown in Figure 3. Category 3 includes contained or confined disposal with potential for contamination of the receiving water column. These proposed testing requirements call for evaluation of short-term water column impacts of disposal area effluents. Predicted contaminant concentrations based on the results of a modified elutriate test can be used with appropriate water quality standards to determine the required dimensions of a mixing zone necessary to achieve an acceptable level in the discharge receiving waters. Procedures for evaluating mixing zones have been reported by the Environmental Effects Laboratory (1976), Environmental Protection Agency/Corps of Engineers (1977), and MacIntyre (1985).

Data Requirements

10. Data requirements for prediction of effluent quality include those pertaining to operational considerations (i.e. disposal site characteristics and dredge characteristics) and those pertaining to the properties of the dredged material (i.e. contaminant release characteristics and sedimentation characteristics). Data relating to operational considerations are usually determined by the disposal area design and by past experience in dredging and disposal activities for the project under consideration or for similar

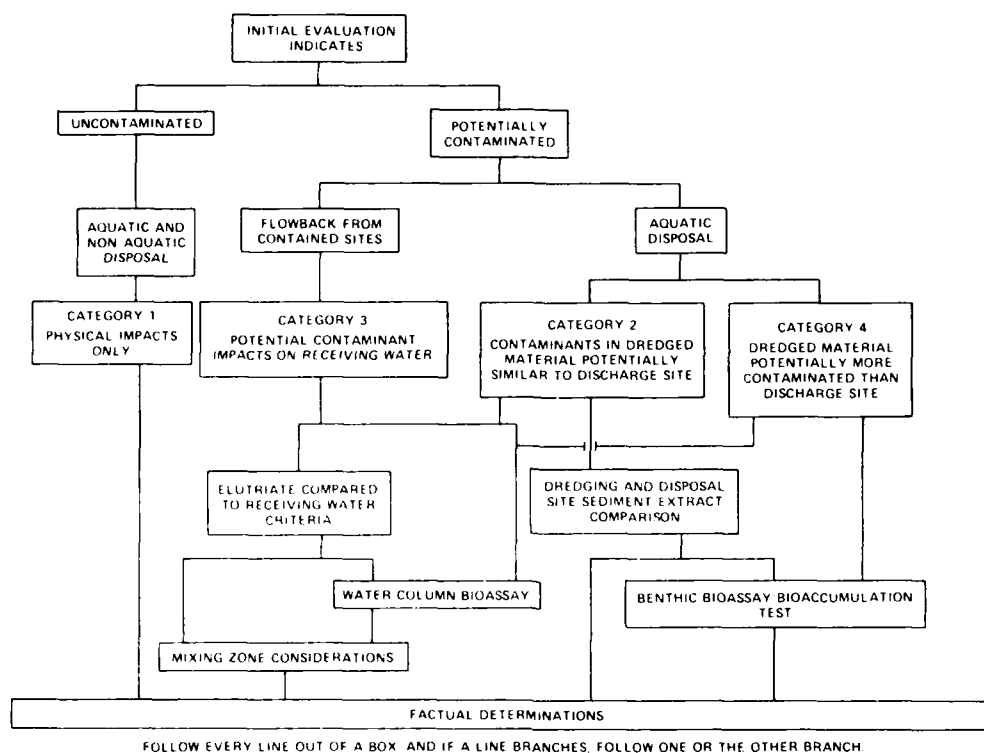


Figure 3. Testing flowchart (EPA 1980b)

projects. Data relating to the dredged material characteristics must be obtained by sampling the sediments to be dredged and testing them.

11. A summary of the data requirements for effluent quality prediction is given in Table 1. Some of the data must be determined in the design or evaluation of the site using procedures described by Montgomery (1978) and Palermo, Montgomery, and Poindexter (1978). The remaining data must be developed using the procedures described in this paper.

Disposal area design

12. When the quality of the effluent from a disposal area is of concern, the design, operation, and management of the site should be carefully controlled. This includes aspects relating to both the volume required for effective sedimentation and the storage capacity of the site. Procedures for such evaluations are presented by Montgomery (1978) and Palermo, Montgomery, and Poindexter (1978), and should be considered prior to the prediction of the quality of the effluent for the project. These design procedures will determine the surface area and ponding depth required to achieve effective sedimentation, the required containment volume for storage (including

Table 1
Summary of Data Requirements* for Prediction of the Quality of
 Effluent from Confined Dredged Material Disposal Areas

Data Required	Symbol	Source of Data
Dredge inflow rate	Q_1	Project information; site design
Dredge inflow solids concentration	C_1	Project information; site design
Ponded area in disposal site	A_p	Project information; site design
Average ponding depth in disposal site and at the weir	D_p, D_{pw}	Project information; site design
Hydraulic efficiency factor	HEF	Dye tracer or theoretical determination
Effluent total suspended solids concentration	SS_{eff}	Laboratory column settling tests
Dissolved concentration of contaminant in effluent	C_{diss}	Modified elutriate tests
Fraction of contaminant in the total suspended solids in effluent	F_{SS}	Modified elutriate tests

* This summary includes only those data required for effluent quality prediction. It is assumed that the disposal area under consideration is designed for effective sedimentation and storage capacity. Data requirements for such design or evaluation are found in Palermo, Montgomery, and Poindexter (1978).

required freeboard), and the proper sizing of weir structures. The prediction of the quality of the effluent is an extension and refinement of the design procedures. A list of data items required from the design evaluation is shown in Table 1.

Sediment characteristics

13. An initial screening for contamination must be performed as outlined in the testing requirements for Section 404 of the Clean Water Act (EPA 1980a). Considerations include but are not limited to:

- a. Potential routes by which contaminants could reasonably have been introduced to the sediments.
- b. Data from previous tests of the material or other similar material in the vicinity, provided the comparisons are still appropriate.

- c. Probability of contamination from surface runoff.
- d. Previous spills of contaminants in the area to be dredged.
- e. Industrial and municipal waste discharges upstream of the area to be dredged.

14. The screening process should identify which contaminants are of concern and which therefore should be considered for subsequent analysis in the modified elutriate testing. The modified elutriate tests and the column settling tests provide the remaining data required for prediction of the quality of the effluent.

Sampling Requirements

15. Samples of channel sediment and water from the proposed dredging site are required for conducting modified elutriate tests and column settling tests, and for characterizing the sediment to be dredged. The level of effort, including number of sampling stations, quantity of material, and any schemes used for compositing samples, is highly project-specific. If at all possible, the sampling operations required for sediment characterization (both physical and chemical), for design and evaluation of the disposal site, and for conducting the modified elutriate tests should be conducted simultaneously to avoid duplication of effort.

16. Normally, sediments from maintenance dredging are more likely to be contaminated and thus are those for which disposal site effluent quality will be of concern. Grab samples are generally satisfactory for obtaining the quantities needed for all testing requirements. Guidance on sampling procedures is found in Palermo, Montgomery, and Poindexter (1978). General guidance on sampling and preservation for chemical characterization purposes is given by Plumb (1981). This guidance should be used for obtaining samples for use in the modified elutriate testing. It should be noted that appropriate precautions for worker health and safety should be taken when sampling and testing contaminated sediments.

Modified Elutriate Test Procedure

17. The modified elutriate tests should be conducted, and appropriate chemical analyses should be performed as soon as possible after sample

collection. The volume of elutriate sample needed for chemical analyses will vary depending upon the number and types of chemical analyses to be conducted. Both dissolved and total concentrations of contaminants must be determined. The volume required for each analysis, the number of parameters measured, and the desired analytical replication will influence the total elutriate sample volume required. A 4-l cylinder is normally used for the test, and the supernatant volume available for sample extraction will vary from approximately 500 to 1,000 ml, depending on the sediment properties, settling times, and initial concentration of the slurry. It may be necessary to composite several extracted sample volumes or to use large diameter cylinders to obtain the total required volume.

Apparatus

18. The following items are required:

- a. Laboratory mixer, preferably with Teflon shaft and blades.
- b. Several 4-l graduated cylinders. Larger cylinders may be used if large sample volumes are required for analytical purposes. Nalgene cylinders are acceptable for testing involving analysis of inorganic compounds such as metals and nutrients. Glass cylinders are required for testing involving analysis of organic compounds.
- c. Assorted glassware for sample extraction and handling.
- d. Compressed air source with deionized water trap and tubing for bubble aeration of slurry.
- e. Vacuum or pressure filtration equipment, including vacuum pump or compressed air source and an appropriate filter holder capable of accommodating 47-, 105-, or 155-mm-diam filters.
- f. Presoaked filters with a 0.45- μ m pore-size diameter.
- g. Plastic sample bottles, 500-ml capacity for storage of water and liquid phase samples for metal and nutrient analyses.
- h. Wide-mouth, 1-gal* capacity glass jars with Teflon-lined screw-type lids for sample mixing. These jars should also be used for sample containers when samples are to be analyzed for pesticides.

19. Prior to use, all glassware, filtration equipment, and filters should be thoroughly cleaned. Wash all glassware with detergent, rinse five times with tap water, place in a clean 10-percent (or stronger) HCl acid bath for a minimum of 4 hr, rinse five times with tap water, and then rinse five

* A table of factors for converting non-SI units of measurement to SI (metric) units is presented on page 3.

times with distilled or deionized water. Soak filters for a minimum of 2 hr in a 5-M HCl bath, and then rinse 10 times with distilled water. It is also a good practice to discard the first 50 ml of water or liquid phase filtered. Wash all glassware to be used in preparation and analysis of pesticide residues using the eight-step procedure given in EPA (1974).

Test procedure

20. The step-by-step procedure for conducting the modified elutriate test is outlined below. An example calculation procedure is also given in the following paragraphs.

21. Step 1 - Slurry preparation. The sediment and water from the proposed dredging site should be mixed to a concentration approximately equal to the expected average field inflow concentration. If estimates of the average field inflow concentration cannot be made based on past data, a slurry concentration of 150 g/l (dry weight basis) should be used. Predetermine the concentration of the well-mixed sediment in grams per litre (dry weight basis) by oven drying a small subsample of known volume. Each 4-l cylinder to be filled will require a mixed slurry volume of 3-3/4 l. The volumes of sediment and water to be mixed for a 3-3/4-l slurry volume may be calculated using the following expressions:

$$V_{\text{sediment}} = 3.75 \frac{C_{\text{slurry}}}{C_{\text{sediment}}} \quad (1)$$

and

$$V_{\text{water}} = 3.75 - V_{\text{sediment}} \quad (2)$$

where

V_{sediment} = volume of sediment, in l

3.75 = volume of slurry for 4-l cylinder, l

C_{slurry} = desired concentration of slurry, g/l (dry weight basis)

C_{sediment} = predetermined concentration of sediment, g/l (dry weight basis)

V_{water} = volume of dredging site water, in l

22. Step 2 - Mixing. Mix the 3-3/4 l of slurry by placing appropriate volumes of sediment and water from the proposed dredging site in a 1-gal

glass jar and mixing for 5 min with the laboratory mixer. The slurry should be mixed to a uniform consistency, with no unmixed agglomerations of sediment.

23. Step 3 - Aeration. The prepared slurry must be aerated to ensure that oxidizing conditions will be present in the supernatant water during the subsequent settling phase. Bubble aeration is therefore used as a method of sample agitation. Pour the mixed slurry into a 4-l graduated cylinder. Attach glass tubing to the aeration source and insert the tubing to the bottom of the cylinder. The tubing can be held in place by insertion through a predrilled No. 4 stopper placed in the top of the cylinder. Compressed air should be passed through a deionized water trap, through the tubing, and bubbled through the slurry. The flow rate should be adjusted to agitate the mixture vigorously for 1 hr.

24. Step 4 - Settling. Remove the tubing, and allow the aerated slurry to undergo quiescent settling for a time period equal to the anticipated field mean retention time, up to a maximum of 24 hr. If the field mean retention time is not known, allow settling for 24 hr. Guidance for estimating the field mean retention is given in later paragraphs.

25. Step 5 - Sample extraction. After the appropriate period of quiescent settling, an interface will usually be evident between the supernatant water, with a low concentration of suspended solids above, and the more concentrated settled material below the interface. Samples of the supernatant water should be extracted from the cylinder at a point midway between the water surface and interface using syringe and tubing. Care should be taken not to resuspend the settled material.

26. Step 6 - Sample preservation and analyses. The sample should be analyzed as soon as possible after extraction. Total suspended solids in milligrams per litre and dissolved and total concentrations of desired analytes in milligrams per litre should be determined. The fraction of analytes in the total suspended solids in milligrams per kilogram SS can then be calculated for appropriate analytes. Filtration using 0.45- μ m filters should be used to obtain subsamples for analysis of dissolved concentrations. Samples to be analyzed for dissolved pesticides or polychlorinated biphenyls (PCBs) must be free of particles but should not be filtered due to the tendency for these materials to adsorb on the filter. However, particulate matter can be removed before analysis by high-speed centrifugation at

10,000 times gravity using Teflon, glass, or aluminum centrifuge tubes (Fulk et al. 1975). The total suspended solids concentration can also be determined by filtration (0.45 μ m). The fraction of analytes in the total suspended solids may be calculated in terms of milligrams per kilogram SS using Equation 3,

$$F_{SS} = (1 \times 10^6) \frac{C_{total} - C_{diss}}{SS} \quad (3)$$

where

F_{SS} = fraction of analyte in the total suspended solids, mg analyte/kg of suspended solids

C_{total} = total concentration, mg analyte/l of sample

C_{diss} = dissolved concentration mg, analyte/l of sample

SS = total suspended solids concentration, mg solids/l of sample

27. Subsamples for analyses of total concentrations should undergo appropriate digestion prior to analysis. All digestion and chemical analyses should be performed using accepted procedures (American Public Health Association 1981; EPA 1974, 1979).

28. Samples to be analyzed for pesticides or PCBs should immediately undergo solvent extraction. The extract may then be held in clean uncontaminating containers for periods of up to 3 or 4 weeks at -15° to -20° C before the analyses are performed.

29. Samples for metals analysis should be preserved immediately by lowering the pH to <2 with 3 to 5 ml of concentrated nitric acid per litre (EPA 1979). High purity acid, either purchased commercially or prepared by a subboiling unit, must be used.

30. Nutrient analyses should be conducted as soon as possible. Acidification with H_2SO_4 to pH <2 and storage at 4° C may allow the sample to be held for a maximum of 24 hr for ammonia nitrogen, Kjeldahl nitrogen, and nitrate nitrogen analyses (EPA 1979). Storage at 4° C will allow holding of samples to be analyzed for dissolved orthophosphate and total dissolved

phosphorus for up to 24 hr. Subsamples to be analyzed for cyanide should be preserved with 2 ml of 10 N sodium hydroxide per litre of sample (pH >12) (EPA 1979).

Column Settling Test Procedure

31. Sedimentation tests, performed in 8-in.-diam ported columns, as shown in Figure 4, are necessary to provide data for design or evaluation of disposal areas for retention of suspended solids. These tests are designed to define the settling behavior of a particular sediment and to provide information concerning the volumes occupied by newly placed layers of dredged material.

32. Sedimentation of freshwater slurries of concentration less than 100 g/l can generally be characterized as flocculent settling. As slurry concentrations are increased, the sedimentation process may be characterized as a zone settling process, in which a clearly defined interface is formed between the clarified supernatant water and the more concentrated settled material. Zone settling also occurs when the sediment/water salinity is approximately 3 ppt or greater. Recent studies (Palermo, in publication) have shown that flocculent settling also describes the behavior of residual suspended solids in the clarified supernatant water above the sediment/water interface for slurries exhibiting an interface. The procedures described below include those modifications of the procedures described by Montgomery (1978) and Palermo, Montgomery, and Poindexter (1978) required to define the flocculation process describing the sedimentation of suspended solids above the settled material/water interface under zone setting conditions. The settling test procedures as modified consist of withdrawing samples from the settling column at various depths and times and measuring the concentrations of suspended solids, and of timing the fall of the liquid/solids interface. This procedure is a combination of both the zone and flocculent test procedures described by Palermo, Montgomery, and Poindexter (1978).

Apparatus

33. A settling column such as shown in Figure 4 is used. The test column depth should approximate the effective settling depth of the proposed disposal area. A practical limit on the depth of the test is 6 ft. The column should be at least 8 in. in diameter with interchangeable sections and

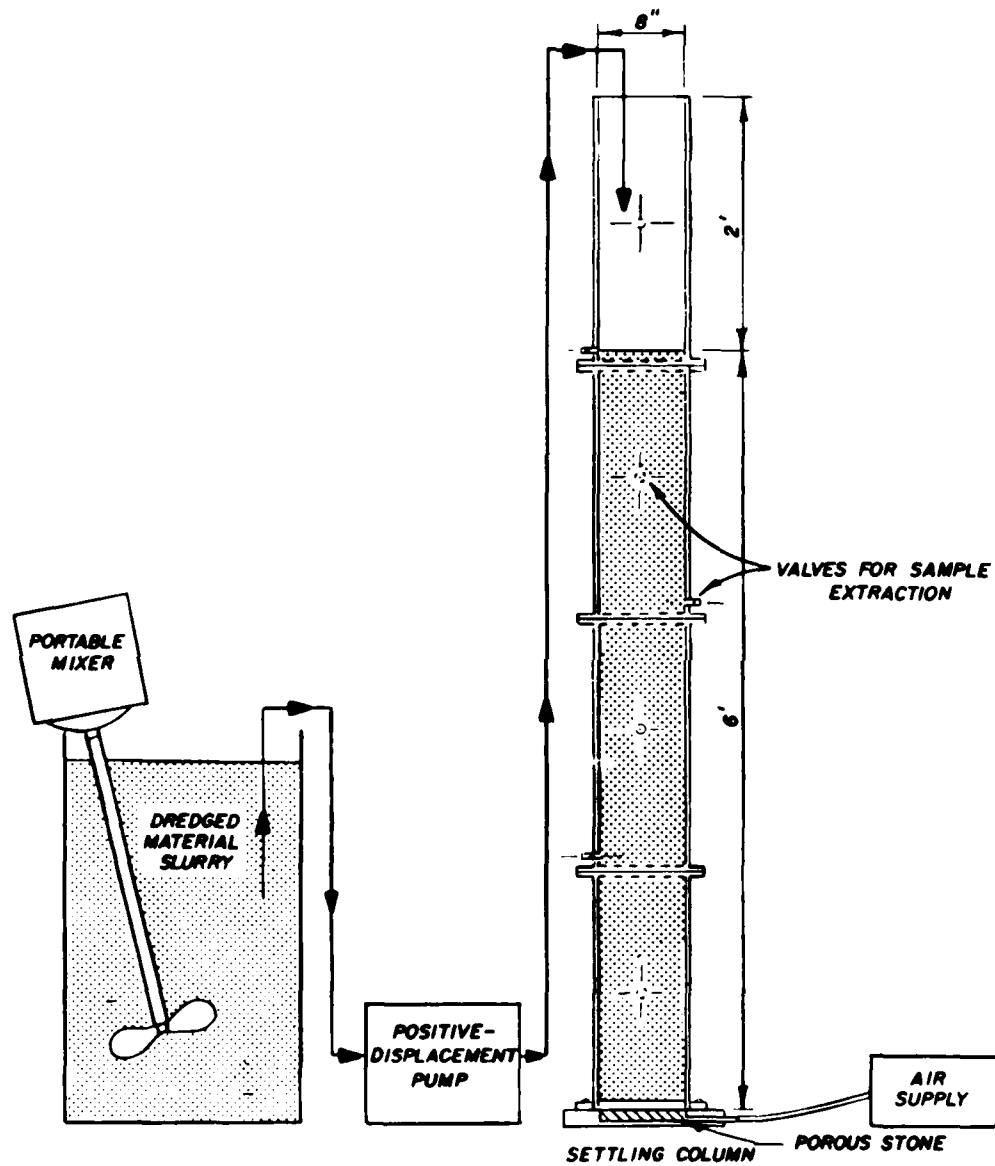


Figure 4. Schematic diagram of apparatus for column settling tests

with sample ports at 1-ft or closer intervals in the lower 3 ft and at 1/2-ft intervals in the upper 3 ft. The column should have provisions to bubble air from the bottom to keep the slurry mixed during the column filling period. Shop drawings for construction of the test columns are available from the US Army Engineer Waterways Experiment Station.

Flocculent settling test procedure

34. Test data required to design or evaluate a disposal area in which flocculent settling occurs and to predict the concentration of suspended solids in the effluent can be obtained using the procedures described by Montgomery (1978) and Palermo, Montgomery, and Poindexter (1978). These procedures allow the prediction of the concentration of suspended solids in the effluent SS_{eff} as a function of retention time.

Zone settling test procedure

35. Information required to design or evaluate a disposal area in which zone settling occurs can be obtained by a series of zone settling tests (Montgomery 1978; Palermo, Montgomery, and Poindexter 1978). One of the tests should be performed on sediment/water slurries at a concentration equal to the expected mean field inflow concentration. This test should be continued for a period of at least 15 days to provide data for estimating volume requirements. This test is also the test which should be used to obtain data for prediction of effluent suspended solids concentrations using the combined zone/flocculent settling test procedures.

Zone/flocculent settling test procedure

36. The zone/flocculent test is simply both the zone and flocculent tests combined to allow prediction of effluent suspended solids in cases where zone settling is the major settling process for the slurry being tested. The stepwise procedure for this test is described in the following paragraphs.

37. Step 1 - Slurry preparation and loading. Mix the sediment slurry to the desired suspended solids concentration in a container with sufficient volume to fill the test column. The test should be performed at the concentration selected to represent the anticipated concentration of the dredged material influent C_1 . Field studies indicate that, for maintenance dredging in fine-grained material, the influent concentration will average about 150 g/l. This value may be used for C_1 if no better data are available.

38. Step 2 - Settling and sampling. Begin extracting samples from the

side ports for determination of suspended solids concentration. Since suspended solids concentrations in the extracted samples are likely to be less than 100 mg/l, precision in determining the concentrations is necessary to avoid excessive random error in the results. For sediments exhibiting zone settling behavior, an interface will form between the more concentrated settled material and the clarified supernatant water. The first sample should be extracted immediately after the interface has fallen sufficiently below the uppermost port to allow extraction. This sample can usually be extracted within a few hours after initiation of the test, depending on the initial slurry concentration and the spacing of the ports. Record the time of extraction and port height for each port sample taken. As the interface continues to fall, extract samples from all ports above the interface at regular time intervals. Substantial reductions of suspended solids will occur during the early part of the test, but reductions will lessen at longer retention times. Therefore, the intervals can be extended as the test progresses. A suggested sequence of intervals would be 2, 4, 8, 12, 24, 48, 96 hr, etc. The samples should continue to be taken throughout the 15-day test, or until the suspended solids concentration of the extracted samples shows no decrease.

Data analysis

39. For the flocculent settling case, the procedures for data analyses given by Montgomery (1978) and Palermo, Montgomery, and Poindexter (1978) may be used. For the zone settling case, flocculent settling behavior governs in the supernatant water above the interface. Therefore, a flocculent data analyses procedure, as outlined in the following paragraphs, is required. Example calculations are also shown in the following paragraphs.

40. Step 1. Arrange the flocculent settling test data from the laboratory test as shown in Table 3 in Example 1, and compute values of the depth of sampling below the fluid surface z . In computing the fractions of suspended solids remaining ϕ , the highest concentration of the first port samples taken is considered the initial concentration SS_0 .

41. Step 2. Plot the values of ϕ and z using the data from the table as shown in Figure 5 in Example 1, forming a concentration profile diagram. Concentration-depth profiles should be plotted for each time of sample extraction.

42. Step 3. Use the concentration profile diagram to graphically determine percentages of suspended solids removed R for the various time

intervals for any desired ponding depth D_{pw} . This is done by graphically determining the areas to the right of each concentration-depth profile and its ratio to the total area above the depth D_{pw} . The removal percentage is:

$$R = \frac{\text{Area to right of profile}}{\text{Total area}} \quad (100) \quad (4)$$

43. Step 4. Compute the percentage P remaining as simply 100 minus the percentage removed, or

$$P = 100 - R \quad (5)$$

44. Step 5. Compute values for suspended solids for each time of extraction as

$$SS_t = P_t(SS_o) \quad (6)$$

Arrange the data as shown in Table 4 in Example 1.

45. Step 6. Plot a relationship for suspended solids concentration versus time using the value for each time of extraction, as shown in Figure 6 in Example 1. An exponential or power curve fitted through the data points is recommended.

46. By repeating steps 4 through 6 for each of several values of D_{pw} , a family of curves showing suspended solids remaining versus retention time for each of several assumed ponding depths may be developed. These curves may be used for prediction of effluent suspended solids concentrations under ideal, quiescent settling conditions for any estimated ponding depth and field mean retention time. Simply enter a curve with the estimated field mean retention time T_d , and select the value of effluent suspended solids predicted by the column test SS_{col} . Guidance for adjusting the value derived from the column test for anticipated resuspension and for estimated field mean retention time is given in the following paragraphs.

Determination of Effluent Suspended Solids Concentration

47. A prediction of the concentration of total suspended solids in the effluent must consider the anticipated actual mean retention time in the disposal area and must account for possible resuspension of settled material because of wind-generated turbulence. The relationship of supernatant suspended solids versus time developed from the column settling test is based on quiescent settling conditions found in the laboratory. The anticipated actual mean retention time in the disposal area under consideration can be used to determine a predicted suspended solids concentration from the relationship. This predicted value can be considered a minimum value which could only be achieved in the field if there were little or no turbulence or resuspension of settled material. However, an adjustment for anticipated resuspension is necessary for real conditions. The minimum expected value and the value adjusted for resuspension would provide a range of anticipated suspended solids concentrations for use in predicting the total concentrations of contaminants in the effluent. The value adjusted for anticipated resuspension is

$$SS_{eff} = SS_{col} \times RF \quad (7)$$

where

SS_{eff} = suspended solids concentration of effluent considering anticipated resuspension, mg suspended solids/l of water

SS_{col} = suspended solids concentration of effluent as estimated from column settling tests, mg suspended solids/l of water

RF = resuspension factor selected from Table 2

Table 2 summarizes recommended resuspension factors based on comparisons of suspended solids concentrations predicted from column settling tests and field data from a number of sites with varying site conditions. For dredged material slurries exhibiting flocculent settling behavior, the concentration of particles in the ponded water is on the order of 1 g/l or higher. The resuspension resulting from normal wind conditions will not significantly increase this concentration. Therefore, an adjustment for resuspension is not required for the flocculent settling case.

Table 2
Recommended Resuspension Factors for Various Poned Areas and Depths

<u>Anticipated Poned Area</u>	<u>Resuspension Factor for</u> <u>Anticipated Average Poned Depth</u>	
	<u>Less than 2 ft</u>	<u>2 ft or Greater</u>
Less than 100 acres	2.0	1.5
Greater than 100 acres	2.5	2.0

Determination of Field Mean Retention Time

48. Estimates of the field mean retention time for expected operational conditions are required for selecting appropriate settling times in the modified elutriate test and for determination of suspended solids concentrations in the effluent. Estimates of the retention time must consider the hydraulic efficiency of the disposal area, defined as the ratio of mean retention time to theoretical volumetric retention time. Field mean retention time T_d can be estimated for a given flow rate and ponding conditions by applying a hydraulic efficiency factor to the theoretical detention time as follows:

$$T_d = \frac{T}{(HEF)} \quad (8)$$

where

T_d = mean detention time, hr

T = theoretical detention time, hr

HEF = hydraulic efficiency factor (HEF > 1.0) defined as the inverse of the hydraulic efficiency

The theoretical detention time is calculated from Equation 9.

$$T = \frac{V}{Q_i} \quad (12.1) = \frac{A D}{Q_i} \quad (12.1) \quad (9)$$

where

V_p = volume ponded, acre-ft

Q_i = average inflow rate, cfs

A_p = area ponded, acres

D_p = average depth of ponding, ft

12.1 = conversion factor, acre-ft/cfs to hr

49. The hydraulic efficiency factor can be estimated by several methods. The most accurate estimate is made possible from field dye tracer data previously obtained at the site under operational conditions similar to those for the operation under consideration. Guidance for conducting such field tests is presented by Schroeder et al. (in preparation). This approach can only be considered for existing sites.

50. Hydraulic flow models can also be used to estimate the efficiency factor. Koussis, Saenz, and Thackston (1982) recommended steady-state, two-dimensional models for such evaluations. Development of such techniques is still under study (Schroeder et al., in preparation).

51. In the absence of dye tracer data or values obtained from other theoretical approaches, the HEF can be assumed based on values obtained by dye tracer studies at similar sites and under similar conditions. Montgomery (1978) recommended a value for HEF of 2.25 based on field studies conducted at several sites.

Calculation of Total Concentrations of Contaminants

52. The modified elutriate test procedure estimates dissolved contaminant concentrations in milligrams per litre and fractions of contaminants in the total suspended solids in milligrams per kilogram SS under quiescent settling conditions and accounts for geochemical changes occurring in the disposal area during active disposal operations. Using these test results, the total contaminant concentration in milligrams per litre in the effluent may be estimated as

$$C_{\text{total}} = C_{\text{diss}} \frac{F_{\text{ss}} S_{\text{eff}}}{(1 \times 10^6)} \quad (10)$$

where

C_{total} = estimated total concentration in effluent, mg analyte/l of water

C_{diss} = dissolved concentration determined by modified elutriate tests, mg analyte/l of sample

F_{SS} = fraction of analyte in the total suspended solids calculated from modified elutriate results, mg analyte/kg of suspended solids

SS_{eff} = suspended solids concentration of effluent estimated from evaluation of sedimentation performance, mg suspended solids/l of water

(1×10^6) = conversion factor, mg/mg to mg/kg

The acceptability of the proposed confined disposal operation can then be evaluated by comparing the predicted total contaminant concentrations for the various pollutants with applicable water quality standards, considering an appropriate mixing zone. Example calculations illustrating the above procedures are given in the following paragraphs.

Example 1: Evaluation of Effluent Water Quality
for an Existing Disposal Area

Project information

53. Dredged material from a maintenance project will be placed in an existing disposal site. The ponded area will be approximately 35 acres. The design, using procedures described by Montgomery (1978) and Palermo, Montgomery, and Poindexter (1978), indicated that the surface area is adequate for sedimentation if a minimum ponding depth of 2 ft is maintained. The dredging equipment and pumping conditions anticipated will result in a flow rate of approximately 30 cfs. A dye tracer test was previously run at this disposal site under similar operational conditions, and the field mean retention time was 20 hr. Previous sampling of inflow from the dredge pipe under similar conditions indicated that the influent solids concentration was approximately 150 g/l.

54. The quality of effluent must be predicted and compared with applicable water quality standards so that the acceptability of the proposed discharge may be evaluated. A mixing evaluation was conducted, and a dilution factor of 38 was determined for the allowable mixing zone. The water quality standard for copper at the perimeter of the mixing zone was set at 0.004 mg/l (whole water). The concentrations of copper in the pond effluent (at the

point of discharge) must therefore be less than 0.15 mg/l to meet the standards, prior to application of the appropriate mixing zone.

Modified elutriate testing

55. Modified elutriate tests were conducted on samples of sediment and site water from three stations at the site. The modified elutriate tests were run at the anticipated influent concentration, in this case 150 g/l. Sediment samples for each sampling station to be tested were homogenized. For one of the homogenized samples, a sediment concentration of 450 g/l was determined by oven drying a sample of known volume. The volumes of sediment and water mixed for this sample for a 3-3/4-l slurry volume were determined using Equations 1 and 2 as

$$V_{\text{sediment}} = 3.75 \frac{C_{\text{slurry}}}{C_{\text{sediment}}} = 3.75 \frac{150}{450} = 1.25 \text{ l}$$

and

$$V_{\text{water}} = 3.75 - V_{\text{sediment}} = 3.75 - 1.25 = 2.50 \text{ l}$$

56. The modified elutriate tests were completed as described previously. Retention time used in the tests was equal to the anticipated field mean retention time of 20 hr. Samples were extracted for the replicate tests and analyzed for total suspended solids, and both dissolved and total concentrations of desired parameters. The total suspended solids concentration in one of the extracted samples was 40 mg/l. The concentration of dissolved copper in this sample was 0.06 mg/l, while the total concentration of copper was 0.08 mg/l. The fraction of copper in the total suspended solids for this sample was determined using Equation 3 as

$$F_{\text{SS}} = (1 \times 10^6) \frac{C_{\text{total}} - C_{\text{diss}}}{\text{SS}} = (1 \times 10^6) \frac{0.08 - 0.06}{40}$$
$$= 500 \text{ mg/kg SS (replicate mean = 510 mg/kg SS)}$$

57. These calculations were repeated for other replicate tests and the

average dissolved copper concentration and particulate copper fraction were found to be 0.06 mg/l and 510 mg/kg SS, respectively.

Column settling tests

58. Samples from all stations were homogenized into a composite for column settling tests. The test used for prediction of effluent suspended solids was run at a slurry concentration of 150 g/l, equal to the anticipated influent slurry concentration. The interface was formed early in the test. Samples were extracted from all cleared ports at 3, 7, 14, 24, and 48 hr. Data for the solids concentrations and for various depths and extraction times are shown in Table 3.

59. The concentration-depth profile diagram was then constructed from the data, and is shown in Figure 5. Ratios of suspended solids removed as a function of time were then determined graphically using the step-by-step procedure described previously. Since an interface formed in the test, the slurry mass was undergoing zone settling. Therefore, the initial supernatant solids concentration SS_0 was assumed to be the highest concentration of the first samples taken, 169 mg/l. The concentration-depth profile diagram was therefore constructed using 169 mg/l as $\phi = 100$ percent. The lower horizontal boundaries for the area determinations corresponded to a range of assumed depths of withdrawal influence at the outlet weir, in this case 1, 2, and 3 ft. An example calculation of the removal ratio for the concentration-depth profile at $t = 14$ hr and a depth of influence of 2 ft using Equation 4 is

$$R_{14} = \frac{\text{Area to right of the profile}}{\text{Total area}} = \frac{\text{Area 1230*}}{\text{Area 1240}} = 0.78$$

The areas were determined by planimeter. The portion remaining at $t = 14$ hr is found using Equation 5 to be

$$P_{14} = 1 - R_{14} = 1 - 0.78 = 0.22$$

The value for the suspended solids remaining is found using Equation 6 to be

* Areas are designated by circled numbers in Figure 5.

Table 3
Observed Flocculent Settling Data

<u>Sample Extraction Time t (hr)</u>	<u>Depth of Sample Extraction z (ft)</u>	<u>Suspended Solids SS (mg/l)</u>	<u>Fraction of Initial SS ϕ (percent)</u>
3	0.2	93	55
3	1.0	169	100
7	1.0	100	59
7	2.0	105	62
14	1.0	45	27
14	2.0	43	25
14	3.0	50	30
24	1.0	19	11
24	2.0	18	11
24	3.0	20	12
48	1.0	15	9
48	2.0	7	4
48	3.0	14	8

Table 4
Percentage of Initial Concentration and Suspended Solids
Concentrations vs. Time, Assumed Depth of
Influence of 2 ft

<u>Sample Extraction Time, t (hr)</u>	<u>Removal Percentage, R_t</u>	<u>Remaining Percentage, P_t</u>	<u>Suspended Solids SS (mg/l)</u>
3	14	86	145
7	47	53	90
14	78	22	37
24	90	10	17
48	94	6	10

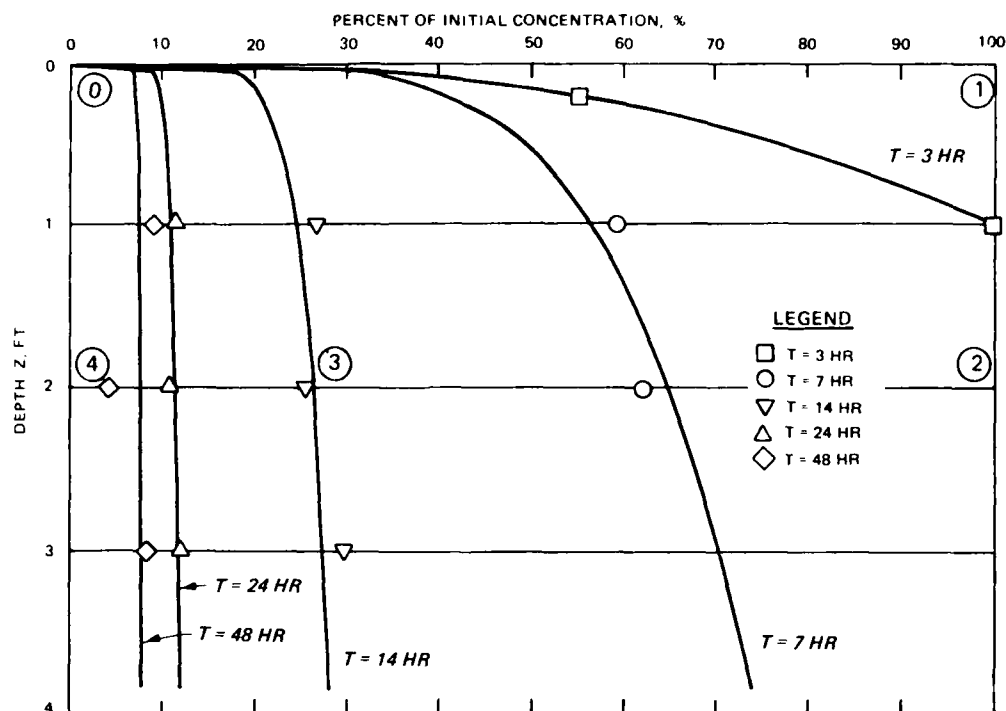


Figure 5. Concentration profile diagram

$$SS_{14} = P_{14} (SS_0) = 0.22 (169) = 37 \text{ mg/l}$$

Values at other times were determined in a similar manner. The summary data are shown in Table 4. Similar calculations for other assumed ponding depths were made. Curves were fitted to the data for total suspended solids versus retention time for depths of influence of 1, 2, and 3 ft and are shown in Figure 6.

Prediction of effluent suspended solids concentration

60. A value for the estimated effluent suspended solids can be determined for quiescent settling conditions using the column test relationship. In this case, the field mean retention time of 20 hr corresponds to a suspended solids concentration of 24 mg/l, as shown in Figure 6. This value should be adjusted for anticipated resuspension using the factors shown in Table 2. In this case, for a surface area less than 100 acres and an assumed average ponding depth of 2 ft, the resuspension factor is 1.5. The predicted

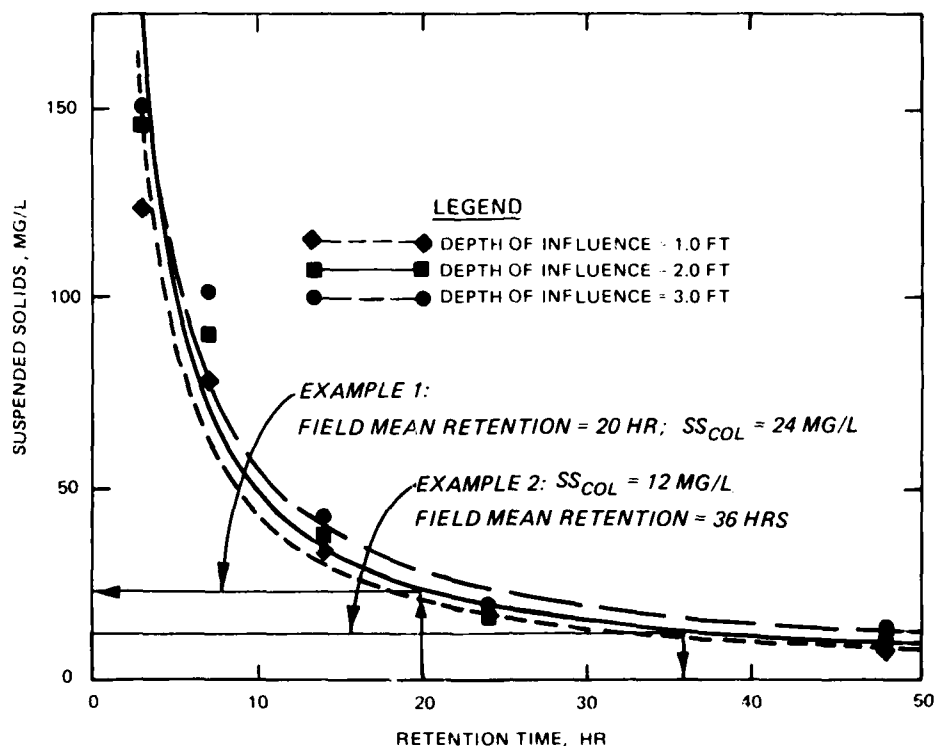


Figure 6. Plot of supernatant suspended solids concentration versus time from column settling tests

total suspended solids concentration in the effluent is calculated using Equation 7 as

$$SS_{eff} = SS_{col} \times RF = 24 \text{ mg/l} \times 1.5 = 36 \text{ mg/l}$$

Prediction of contaminant concentrations

61. The results of the modified elutriate tests estimated that the concentration of dissolved copper would be 0.06 mg/l, and that the fraction of copper in the total suspended solids would be 510 mg/kg SS. The estimated total suspended solids concentration in the effluent is 36 mg/l. The estimated concentration of total copper in the effluent is then calculated using Equation 10 to be:

$$C_{\text{total}} = C_{\text{diss}} + \frac{F_{\text{SS}} \text{ SS}_{\text{eff}}}{(1 \times 10^6)} = 0.06 + \frac{(510) (36)}{(1 \times 10^6)}$$

$$= 0.078 \text{ mg/l (call it 0.08 mg/l)}$$

62. The estimated concentrations of other parameters in the disposal area effluent can be determined in a similar manner. The acceptability of the proposed discharge can be evaluated by comparing the estimated effluent concentrations with applicable water quality standards, considering an appropriate mixing zone. For total copper, the estimated concentration of 0.08 mg/l at the point of discharge is less than the limiting value of 0.15 mg/l. The discharge would therefore be acceptable.

Example 2: Determination of Disposal Area Requirements to Meet a Given Effluent Quality Standard

Project information

63. A disposal area is planned for contaminated sediment from a small maintenance dredging project. Dredging equipment traditionally used in the project area is capable of flow rates up to 15 cfs. Available real estate in the project vicinity is scarce, with the maximum available area limited to 60 acres. The disposal area required to meet applicable water quality standards must be determined. The design, using procedures described by Montgomery (1978) and Palermo, Montgomery, and Poindexter (1978), indicated that a minimum ponded surface area of 20 acres was required for effective sedimentation, assuming a flow rate of 15 cfs and an assumed minimum ponding depth of 2 ft. A mixing evaluation was conducted and a dilution factor of 60 was estimated for the allowable mixing zone. The water quality standard for PCB at the perimeter of the mixing zone was set at 0.00003 mg/l. The concentrations of PCB in the pond effluent (at the point of discharge) must therefore be less than 0.0018 mg/l to meet the standards, considering an appropriate mixing zone.

Modified elutriate testing

64. Modified elutriate tests were conducted and calculations were made as described for Example 1. For this example, the anticipated mean field retention time is not known beforehand, so the maximum laboratory retention

of 24 hr should be used for the tests. Since the inflow concentration is not known beforehand, the tests should be run at a slurry concentration of 150 g/l. Results for the replicate tests for this example are 0.001 mg/l for the concentration of dissolved PCB and 44 mg/kg SS for the fraction of PCB in the total suspended solids.

Column settling tests

65. Column settling tests were performed, and the resulting concentration-depth profile was developed as was illustrated in Example 1. The column tests were run at a concentration of 150 g/l for this example. For simplicity, the test results from column tests used in the first example will also be used in this example (see Figure 6).

Determination of allowed effluent suspended solids concentrations

66. Since this example requires determination of the disposal site characteristics necessary to meet a given water quality standard, the calculations would proceed in a manner similar to Example 1, but in reverse sequence. The concentration of effluent suspended solids required to meet water quality standards must first be determined. For total PCB, the standard (at the point of discharge) is 0.0018 mg/l. The allowed solids concentration allowed to meet this standard is calculated using Equation 10,

$$C_{\text{total}} = C_{\text{diss}} + \frac{F_{\text{SS}} \text{ SS}_{\text{eff}}}{(1 \times 10^6)}$$

or transposed,

$$\text{SS}_{\text{eff}} = \frac{(1 \times 10^6)}{F_{\text{SS}}} (C_{\text{total}} - C_{\text{diss}}) = \frac{1 \times 10^6}{44.0} (0.0018 - 0.001) = 18 \text{ mg/l}$$

Based on the modified elutriate test data, the effluent suspended solids concentration cannot exceed 18 mg/l without exceeding the standard for PCB. Similar determinations should also be made for other contaminants being considered in order to define the minimum value for the required effluent suspended solids concentration. For this example, assume that 18 mg/l is the minimum value.

67. An appropriate value should be selected from Table 2 for the resuspension factor. The minimum ponding depth of 2 ft required by the site design was selected. A resuspension factor of 1.5 was selected, corresponding to an available area <100 acres and the selected ponding depth of 2 ft.

68. The value of 18 mg/ℓ of SS which must be achieved at the point of discharge includes anticipated resuspension. The corresponding value for total suspended solids concentration under quiescent settling conditions is determined using Equation 7,

$$S_{eff} = SS_{col} \times RF$$

or transposed,

$$SS_{col} = \frac{SS_{eff}}{RF} = \frac{18 \text{ mg/}\ell}{1.5} = 12 \text{ mg/}\ell$$

69. The disposal area must provide a retention time which will allow the necessary sedimentation. The required retention time to achieve 12 mg/ℓ under quiescent settling conditions may be determined from the relationship of suspended solids versus retention time for the laboratory column. Using the concentration profile data and the selected depth of ponding at the weir of 2 ft, the relationship for suspended solids versus field mean retention was developed as was previously shown in Figure 6. Using Figure 6, 12 mg/ℓ corresponds to a field mean retention time of 36 hr. To determine the required disposal site geometry, the theoretical volumetric retention time should be used. Since no other data were available, the hydraulic efficiency factor was assumed to be 2.25. The theoretical volumetric retention time was calculated using Equation 8,

$$T_d = \frac{T}{(HEF)}$$

or transposed,

$$T = T_d (HEF) = 36 (2.25) = 81 \text{ hr}$$

Determination of ponded
volume and surface area

70. The required disposal area ponded volume can now be determined using data on anticipated flow rate and the theoretical volumetric retention time. Since the dredging equipment available in the project area is capable of flow rates up to 15 cfs, the high value should be assumed.

71. The ponded volume required is calculated using Equation 9,

$$T = \frac{V_p}{Q_1} \quad (12.1)$$

or transposed,

$$V_p = \frac{TQ_1}{12.1} = \frac{81 \text{ hr} \times 15 \text{ cfs}}{12.1} = 100 \text{ acre-ft}$$

72. A ponding depth of 2 ft is the minimum allowed. This same depth should be maintained over the entire ponded surface area and at the weir. The disposal site should therefore encompass approximately 50 acres of ponded surface area with an average depth of 2 ft if the dredge selected for the project has an effective flow rate not greater than 15 cfs. The surface area of 50 acres required to meet the water quality standard controls the design instead of the calculated surface area of 20 acres required for effective sedimentation.

PART III: SUMMARY AND RECOMMENDATIONS

Summary

73. An interim technique to be used for predicting the quality of effluent from confined dredged material disposal areas has been presented. The technique relies on modified elutriate tests for predicting the dissolved and particle-associated contaminant concentrations in the effluent and on column settling tests for predicting the effluent suspended solids concentration. Using results from both of these tests, the total concentration of contaminants in the effluent can be predicted. The predictive technique can be applied both to predict the performance of existing sites and to design new sites.

Recommendations

74. The technique presented in this paper should be used on an interim basis for the evaluation of Category 3 (contained or confined disposal with potential for contamination of the receiving water column) material under Section 404 of the Clean Water Act. Comparisons of predictions using the technique with field data should be made under a wide variety of operating conditions. The testing procedures may then be modified if appropriate to improve accuracy and/or precision. This is currently an ongoing effort under the Corps' LEDO Program.

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